SEDIMENTARY FACIES OF THE CRETACEOUS IZUMI TURBIDITE SYSTEM, SOUTHWEST JAPAN — AN EXAMPLE OF TURBIDITE SEDIMENTATION IN AN ELONGATED STRIKE-SLIP TECTONIC BASIN —

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Abstract Turbidites and associated coarse clastic deposits of the Upper Cretaceous (Campanian-Maastrichtian) Izumi Group were deposited in an elongated basin which stepwise extended eastwards because of strike-slip movements along the Median Tectonic Line of the Southwest Japan. The resultant basin-fill is represented by eastward-younging, thick succession. The Group consists basically of stacks of depositional mega-units. Facies associations indicate that the deposits of the mega-unit are organized into the depositional system which consists of main channel (with over-spilled deposits), distributary channel and sheet-flows. Deposition of the Group is considered that stepwise shifting of the basin to the east caused the stacked depositional mega-units younging eastwards.

Introduction

In Late Cretaceous time, strike-slip movements along the Median Tectonic Line of the Southwest Japan produced an east-west trending elongated basin. The basin successively extended eastwards with migration of the locus of deposition. The resultant basin-fill, the Izumi Group (Campanian-Maastrichtian), is represented by eastward-younging, thick succession of turbidites and associated coarse clastic deposits (Tanaka, 1965). The Group crops out in an area of about 300 km long and 15 km wide (Fig. 1). Petrographic studies of the Izumi Group suggest that source terrains were to the north of the basin (Tanaka, 1965; Nishimura, 1984). Paleo-current measurements indicate that the materials derived from northern terrains were distributed in the basin by westward longitudinal flows (Tanaka, 1965; Nishimura, 1984). Such a relationship between source terrain site and main dispersal pattern is common to elongated basin settings controlled by active strike-slip movements (Steel, 1976). Owing to narrowly confined, elongated basin geometry, the depositional system of the Izumi Group is expected to differ from that of a submarine fan of open system. Furthermore, active strike-slip movement is expected to play an important role in lateral organization of sediments. In this paper, I present a depositional model of the Izumi Group as an example of turbidite sedimentation in a tectonically constrained, elongated basin.

Geologic setting

The Izumi Group in the study area forms more than 4000m thick succession consisting of conglomerate, sandstone and mudstone. The Group unconformably overlies the Sennan Pyroclastic Rocks on the north (Fig. 2) and is separated by the Median Tectonic Line on the south from the Sambagawa Metamorphic Rocks. The Group is gently folded, forming a synclinal structure with an axis plunging to the east. Many acidic tuff layers are intercalated in the succession and can be used as marker beds. Ichikawa et al. (1979) classified the Izumi Group of the Izumi Mountains into the northern marginal facies, main facies and southern facies. Out of them, the northern marginal facies and the main facies are distributed in the study area. The northern marginal facies is represented by the Mutsuo Formation consisting of the basal Kasayama Conglomerate Member and

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the overlying Azenotani Mudstone Member (Tanaka, 1965). The main facies, the subject of this study, dominantly comprises basin-fill turbidites, which are stacked into more than 4000 m thick succession.

Paleocurrent measurements in the study area indicate that sediments were deposited mainly by westward- and partly by south- or southwestward-flowing currents (Fig. 3). The paleotransport direction is in accordance with that of the previous studies of the Izumi Group (Tanaka, 1965; Nishimura, 1976, 1984).

**Facies association**

Six facies associations have been recognized in the Izumi Group under discussion (Fig. 4).

**Upper-channel** association

The upper-channel association occurs in the northern part of the study area (Fig. 2). This association wedges itself into the massive mudstone of the northern marginal facies at its eastern end. To the west, the sequence of this association gradually thickens and interferes with the deposits of the lower-channel association.

The upper-channel association consists dominantly of granule- to cobble-conglomerates and coarse-grained sandstones, with rare intercalations of mudstone. Beds frequently show erosional features as revealed by scour and fill, ripped-up mud clasts and amalgamation.

The predominant facies is graded conglomerate-sandstone couplet in beds of 50—200 cm (commonly 70—90 cm) thick (Plate I-1). The lower conglomeratic part consists of granule- to cobble-sized clasts, and is normally graded, passing upward into structureless to crudely subhorizontally stratified sandstone. Some beds show basal inverse grading. Most of beds have a marked erosional surface at the base. Ripped-up mud clasts are scattered in some beds, most commonly in the upper sandy part. These beds are interpreted as deposits of high-density turbidity currents (Lowe, 1982).

Pebby mudstone occurs as beds of 30—200 cm (commonly 90—100 cm) thick. The beds comprise exotic and intraformational clasts sparsely dispersed in a silty matrix with admixed sand (Plate I-2). Predominant intraclast is of sandstone (20—90 cm in diameter); mudstone clasts (less than 10 cm) are also present. Some sandstone

* The author used terms upper- and lower-channel for proximal to distal parts of the channel. It does not mean stratigraphic upper or lower part.
Fig. 2. Facies association map of study area.
clasts, especially slab-like ones, tend to align roughly parallel to the bedding. Some beds have a clast-supported, conglomeratic basal part, in which inverse-to-normal grading is common (Plate I–3). The pebbly mudstones of this facies are inferred to be of cohesive muddy debris flow origin (Lowe, 1982). The presence of isolated sandstone clasts suggests support by viscosity and buoyancy of cohesive debris mass.

Matrix-rich, structureless sandstone occurs as beds of less than 100 cm thick. The beds consist of fine- to coarse-grained sandstone rich in muddy matrix (20 to 30 percent). The beds are ungraded and unstratified. Basal surface of the beds is sharp and flat, and erosive features are quite rare. The sandstone of this facies probably represents deposition from sandy debris flow (Hampton, 1972; Hiscott & Middleton, 1979; Lowe, 1982). Lack of grading and scour marks suggests limited turbulence in the flow. The high-content of muddy matrix suggests a high matrix strength of the fluid phase.

Matrix-poor, structureless sandstone occurs as beds of 30–40 cm thick. The bed consists of well-sorted, fine-to medium-grained sandstone. Some coarse- to very coarse sand grains are dispersed in the bed. The beds are ungraded and unstratified. Bedding surface is consistently flat and erosive features are quite rare. The sandstone of this facies is inferred to be the deposit of the modified grain flows of Lowe (1982). Absence of internal stratification and low-content of muddy matrix are suggestive of limited turbulence and of low matrix strength. Coarse sand grains dispersed in the fine- to medium-grained sandstone indicate that deposition occurred by mass emplacement.

Pebbly mudstone and matrix-rich, structureless sandstone are intercalated randomly in the packets of amalgamated beds of graded conglomerate-sandstone. Matrix-poor, structureless sandstone is quite rare, and occurs as a bundle of a few beds.

This association shows a fining-upward sequence over the entire thickness of the succession. Internally, however, individual facies are complexly interbedded with one another, so that any minor cycles are not recognized.

The characteristics of the upper-channel association are similar to those of the paleo-submarine channel-fill deposits studied by Mutti (1977), Mutti & Recchi Lucchi (1978), Hein & Walker (1982), and others. The presence of abundant large clasts and erosional features reflects deposition from high energy, erosive currents in the channel. An overall fining-upward sequence of this association reflects gradual broadening of the channel with the lapse of time, which probably resulted from active up-building of the channel. Furthermore, lack of internal minor cycles suggests deposition in an active single-channel system without multi-branching, net work channels in it. East-west trending, axial-channel is inferred from paleo-current measurements.

**Lower-channel association**

The lower-channel association occurs in two distinctive levels in the study area. Out of the two, lower occurrence of this association interfingers with the upper-channel association (Fig. 2). Maximum clast size in this association is commonly of the pebble to granule grades. This association shows strong facies affinity with the upper-channel association. The important difference between the upper-channel and lower-channel associations is that the latter comprises finer clasts than the former.

Graded sandstone, the predominant facies, occurs as beds of 30–150 cm thick. Basal part of the layer is made up of granule- to pebble-size
occurs as beds of 30—150 cm thick. Basal part of the layer is made up of granule- to pebble-size clasts. The uppermost part of some beds reveals subhorizontal stratification. Pebby mudstone occurs as beds of 10—100 cm thick. The bed contains fewer amounts of sandstone intraclasts than that in the upper-channel association. Poorly-sorted, coarse- to medium-grained, structureless sandstone occurs as beds of 20—50 cm thick. Pebby mudstone and poorly-sorted, structureless sandstone are randomly intercalated in the packets of graded sandstone as in the upper-channel association.

The lower-channel association is interpreted as channel-fill deposits as in the case of the upper-channel association. This association undoubtedly represents a deposition in the distal part of the channel, as evidenced by the lateral relationship with the upper-channel association and the westward paleo-dispersal.

**Distributary channel association**

Many fining-upward sequences on the order of 10 m thick are recognized in this association (Fig. 4, Plate II-1). A typical fining-upward sequence abruptly starts at a few beds of very thick (1.5—2 m thick), coarse- to very coarse-grained sandstone. These sandstones are massive and show a
poorly developed grading. They are overlain by structureless or crudely subhorizontally stratified, thick-bedded sandstones (50—60 cm thick) with interbeds of thin mudstone (commonly 15 cm thick). The upper part of the sequence is represented by interbedded, thin sandstones and mudstones (up to 40 cm). Sandstones reveal well grading and commonly show the Tab sequence of Bouma (1962). Occasionally intercalated is pebbly mudstone of muddy debris flow origin. The pebbly mudstones are up to 80 cm thick, and are dissimilar to those in the channel associations, lacking in sandstone intraclasts and basal conglomeratic part. These fining-upward sequences are interpreted to have been formed by filling and abandonment of minor channels.

This association is recognized in three distinctive levels in the study area (Fig. 2). Out of them, the lowest occurrence of this association interfingers with the lower-channel association (Fig. 2). From the westward paleo-dispersal direction, the deposits of this association are inferred to have been derived through the channel responsible to organization of the channel associations. The main channel probably distributed into many minor channels (distributary channels), resulting in many fining-upward sequences recognized in this association.

Sheet-flow turbidite association

The succession of this association shows very parallel bedding with consistent interbedding of sandstones and mudstones. The succession is monotonous without any thinning- or thickening-upward motif.

Sandstone is generally medium-grained, and occurs as beds of 10—50 cm thick. Most of sandstone beds are graded, passing upward into the overlying mudstone. Internally the sandstones are structureless, although the uppermost part of many beds reveals a parallel lamination. The basal surface of the sandstone is sharp and flat, seldom showing scours.

The sheet-flow turbidite association is recognized in two distinctive levels in the study area. Out of the two, the lower occurrence of this association interfingers with the distributary channel association (Fig. 2). From the westward paleo-dispersal, it is supposed that the sheet-flow turbidite association was deposited in a more distal environment than the interfering distributary channel association. General absence of basal erosional surfaces and monotonous succession lacking in any cyclic motif represent deposition from non-channelized, sheet flow of turbidity currents.

Distal sheet-flow turbidite association

The distal sheet-flow turbidite association occurs in the central part of the study area (Fig. 2). This association is represented by the succession of monotonous parallel interbedding of sandstones and mudstones, both up to 30 cm thick, without channeling and any cyclic motif. Sandstones are of fine-grained and gradually grade upward into overlying mudstone. Sandstones show the Tab sequence.

The monotonous succession of this association is similar to that of the sheet-flow turbidite association, and represents deposition from sheet-like turbidity currents as in the case of the latter. However, this association consists of thinner and finer-grained sandstones than those of the sheet-flow turbidite association, implying deposition in a more distal environment.

Levee flank association

The levee flank (in the sense used by Winn and Dott, 1979) association is recognized in two distinctive levels in the study area (Fig. 2). Out of the two, the lower occurrence of this association is overlain by the upper-channel association with a local interfingering relationship with it, and has a transitional contact with the underlying deposits of the Azenotani Mudstone Member of the northern marginal facies.

Sandstone beds are up to 60 cm thick (mostly less than 10 cm). Thinly interbedded sandstones and mudstones of this association are similar to those of the distal sheet-flow turbidite association. However, this association consists of coarser sandstones, that is very corase- to fine-grained, than those of the distal sheet-flow turbidite association. The Ta-3 beds of the Bouma sequence are most common; Ta or Tb beds are locally present. The cross laminated division Tc shows occasional sets of climbing-ripple cross lamination. Both upper and lower surfaces of the beds are sharp, and especially lower ones are commonly irregular.
Some beds show lenticular bedding (Plate II–2). Abundant ripped-up mudclasts are contained in most of sandstones.

The characteristics of the levee flank association are similar to those described in previous works as natural levee or inter-channel deposits (Mutti, 1977; Mutti & Recchi Lucchi, 1978; Winn & Dott, 1979; Carter, 1979; Walker, 1985). The presence of ripped-up mudclasts and coarse grain size in spite of thin beds seems more likely in a channel margin setting than in a truly distal environment. The occurrence along the channel-fill deposits of the upper-channel association also suggests deposition near channel margin. This association is considered to represent deposition of sediments spilled over the main channel.

**Depositional model**

On the basis of lateral and stratigraphic relations of the facies associations, it is clear that the upper-channel, lower-channel, distributary channel, sheet-flow turbidite, distal sheet-flow turbidite and levee flank associations form a depositional mega-unit. Three depositional mega-units are stacked in the study area (Fig. 2). The lowest one is complete mega-unit; others are incomplete in the study area. The depositional model of the complete mega-unit is summarized in Fig. 5.

Transition of the facies associations in a mega-unit reveals that the depositional setting passes, in the down current direction, from a main channel with active overspilling to distributary channels, and then to non-channelized sheet flows.

Sediment gravity flows were flowed into a central part of the basin via the main channel. In the case of the studied mega-unit, the upper reach of the main channel cut into the basin southwestwards owing to the slopes on the eastern margin of the basin which dips westward and that of the northern margin of the basin which dips southwards. The influx direction of the main channel into the basin was mainly controlled by the gradient ratio of these two slopes. The upper-channel and lower-channel associations were formed within this main channel. The lower-channel association is a distal representative of the upper-channel association. Lack of internal minor cycles in the main channel deposits and close association of thick overspilled deposits suggest a relatively
stationary position of the channel and active deposition in the single channel without multi-branched, network channels in it. Well-developed overspillled deposits (levee flank association) are indicative of active spill-over of sediments from the channel. Down slope, the main channel branched into many small channels. Filling and abandonment of these channels resulted in vertically stacked, many fining-upward sequences in the distributary channel association. General absence of overspillled deposits in this association suggests frequent channel cutting and channel migration. Further down slope, these distributary channels gradually became shallower and finally disappeared. Consequently, the sediment gravity flows were released from topographic relief of the channel resulting in broadened sheet-like turbidity currents. Monotonous succession of the sheet-flow turbidite and distal sheet-flow turbidite associations were accumulated in this manner. Lack of sequences indicative of depositional lobes suggests gradual transition from confined flow in distributary channels to unconfined, non-channelized sheet flow.

This system gradually reduced its agent probably due to gradual lowering of efficiency of the channel, leading a fining- and thinning-upward mega-unit.

**Discussions and concluding remarks**

The Izumi Group consists basically of stacked depositional mega-units. The mega-unit is formed by the depositional system which consists of a main channel with overspillled deposits, distributary channels and sheet flows to the downcurrent direction. This system gradually reduced its agent owing to the gradual lowering of efficiency of the channel and formed a fining- and thinning-upward mega-unit.

Depositional system of the Izumi Group can be said to be basically similar to that of the submarine fan model (Normark, 1970; Walker, 1978). However, the Izumi system does not show radial fan shape owing to confinement within the narrow basin, as evidenced by the marked longitudinal dispersal pattern. Furthermore, sequences indicative of depositional lobes are not recognized in the Group of the study area. It is probable that distributary channels gradually became shallower and eventually disappeared, resulting in a gradual transition from confined flow to a distributary channel to unconfined, non-channelized sheet flow. Moreover, there is a possibility that plural distributary channels existed contemporaneously for sheet flows spreading out over the entire width of the basin.

The origin of the sedimentary basin of the Izumi Group has now been regarded as a result of active strike-slip movements along the Median Tectonic Line (cf. Taira et al., 1983). It is suggested that strike-slip movements along the Median Tectonic Line caused formation of depression (Fig. 6). On the other hand, curvature of the northern block which due to strike-slip movements of the Median
Tectonic Line, probably formed topographic relief such as uplifting zone at the northeastern region adjacent to the basin (Fig. 6). Such topographically relieved region provided abundant terrigeneous detritus which flowed into the basin and formed a succession of the mega-unit. Continuing strike-slip movements along the Median Tectonic Line caused eastward extension of the basin as a result of successive formations of new depression at the eastern flank of the previous depocenter (Fig. 6). A new mega-unit was formed in this depression to the east of abandoned mega-units one after another; at the same time, it partly overlies the former mega-unit. Such a stacking process resulted in eastward-younging stacks of the mega-units (Fig. 7).

In the Izumi Mountains including the study area, the Group dominantly comprises the distributable channel and sheet-flow turbidite associations with tongues of the channel associations. The occurrence of the distal sheet-flow turbidite association is restricted. Scarcity of the most distal representative, in spite of successive lateral shift of locus of deposition, may be due to uplift of the previous depressional region with eastward shift of a depocenter. As the result, it is expected that large quantities of sediments rapidly fed into this confined basin and was deposited as mainly proximal facies associations.

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References


TAIRA, A., SAITO, Y. and HASHIMOTO, M., 1983: The role
of oblique subduction and strike-slip tectonics in the evolution of Japan. Geodynamics of the Western Pacific-Indonesian Region. Geodynamics Series, 11, 303-316.


WINN, R. D., Jr. and DOTT, R. H. Jr., 1979: Deep-water fan-channel conglomerates of Late Cretaceous age, southern Chile. Sedimentology, 26, 203-228.

* In Japanese with English abstract.
** In Japanese.

＜地名・層名＞
Azenotani Mudstone Member 鶴谷泥岩層
Kasayama Conglomerate Member 笠山隕岩層
Kinyuji River 金熊寺川
Mutsuo Formation 六尾累層
Yamanaka River 山中川

（要旨）


上部白亜系和泉層群は、西南日本の中央構造線の左横ずれ運動によって形成された、段階的に東進する狭長な堆積盆中に堆積したタービダイトとそれに関連する粗粒碎屑岩よりなる。本論では、和泉山脈西部の和泉層群中において、堆積相および堆積相組合わせに基づく検討を行った結果、和泉層群の一堆積単元を認定した。この堆積単元は、主チャネル（ふれあい層堆積を含む）、分流チャネル、ミートロックから構成される堆積システムからもたらされた堆積物よりなる。調査地域には、このような堆積単元の積み重ねが認められる。段階的に東進する堆積盆東端に、このような堆積システムが順次形成され、碎屑物を供給することによって和泉層群が形成されたものと考えられる。

Explanation of Plates

Plate I Sedimentary facies of the upper-channel association.
1. Graded conglomerate-sandstone couplet.
3. Pebby mudstone. Note clast supported, conglomeratic basal part. Abundant ripped-up mudclasts are scattered in the upper part of the bed.

Plate II 1. Distributary channel association. Fining-upward sequences (arrowed) on the order of 10 m thick are recognized.
2. Levee flank association.